# Fermionic Magic Research

Yusheng Zhao && Chengkai Zhu

*<2024-02-25 Sun>*

## Contents



# 1 Motivation

## 1.1 For Others

### 1.1.1 All pure fermionic non–Gaussian states are magic states for matchgate computations

Presumably, quantum computation is more powerful thant classical ones because it can provide certain "quantum-resources". In the NISQ era, where such provided resources are limited, we must use them economically in order to gain the most use out of quantum computers.

One kind of such quantum resource is known as “magic”. It originates from Clifford circuits, a class of classically efficiently simulatable quantum circuits. Clifford circuits are comprised of Clifford gates. When Clifford gates and adaptive measurements are supplied with magic states, we retrieve universal quantum computation. In this paper, they focus on a different kind of magic known as fermionic magic. The concept is similar, you only replace the clifford circuits with Matchgate circuits. Matchgate circuits are those that are created by matchgates. The reason for considering such variant is that states preparable by matchgates circuits are those that correspond to non-interaction fermion states. Therefore, these states can be interpreted physically more directly.

1. Resources

    - Slides

### 1.1.2 Classical simulation of non-Gaussian fermionic circuits

This contains algorithm for simulating Gaussian or non-Gaussian fermionic circuits. Realizing the algorithm seems like merely a muscle workout.

1. Resources There is a QIP 2024 talk: Classical simulation of non-Gaussian fermionic circuits: Beatriz Cardoso Dias and Robert Koenig. Unfortunately, there’s no recording just yet.

### 1.1.3 Improved simulation of quantum circuits dominated by free fermionic operations

This too.

### 1.1.4 Quanta Magazine Entry

`https://www.quantamagazine.org/the-quest-to-quantify-quantumness-20231019/`

## 1.2 For Me

It is often asked what are the some of the most important applications of a quantum computer. Embarrassingly, the answer is a short one. Currently, the only quantum algorithm that provides exponential speed up comparing to the classical counter-part is Shor’s algorithm. Making things even worse, Shor’s algorithm does not solve any problem, it poses more problem in the sense that it will destroy an encryption system that is working.

In response to this, we are looking for a new quantum algorithm that can solve practically useful problems. Finding such an algorithm is not an easy task, especially when we don't know what IS the difference between classical and quantum computing. Therefore, we will have the motivation of understanding what makes a quantum circuit hard to simulate. More specifically, we will have the motivation of understanind it in the setting of fermionic quantum circuits.

## 2 Goal

Implement algorithms for classically simulating fermoinic quantum circuits. This could be done in many different ways, including but not limited to, using ZW-Calculus, algorithms mentioned in paper. This could make way for the later investigation of this area.

## 3 Potential Ideas?

Besides the implementation of an efficient simulator, we need to think about ideas or questions that utilize such simulator.

- `https://arxiv.org/pdf/2402.18665.pdf`
- "Here a density operator is called convex-Gaussian if it is a convex combination of fermionic Gaussian states. The utility of this concept was illustrated in [31] by showing a converse to the fault-tolerance threshold theorem: Sufficiently noisy quantum circuits can be simulated classically because the corresponding states turn out to be convex-Gaussian. A detailed characteriziation of convex-Gaussianity is necessary to translate this into explicit (numerical) threshold estimates. An infinite hierarchy of semidefinite programs was constructed in [31] to detect convex-Gaussianity, and this was subsequently shown to be complete [44]. This hierarchy also provides a way of determining whether a state is close to being convex-Gaussian"

## 4 Time-line

???

## 5 References